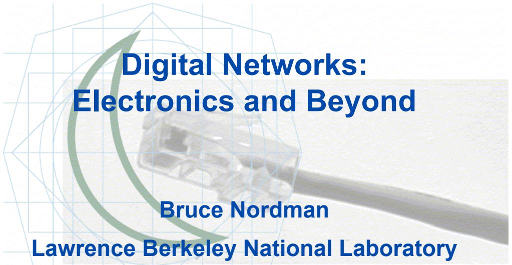
Digital Networks: Electronics and Beyond



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Electronics as an End Use

- Electronics <u>are</u> an end use of electricity

  *"Devices whose primary function is **Information** (obtain, store, manage, present)"*

  –Includes both Information Technology (IT) and Consumer Electronics (CE)

  –Much of this digitally networked already

- Conventional end uses (HVAC, lighting, appliances, …) all based in <u>physics</u>
- Electronics based in <u>information</u>
- (don't forget Miscellaneous)

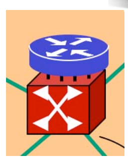
Overview

Electronic Networks

- How much energy does "The Internet" use
- Some things we know
- How to think about Networks and Energy
- Current projects

Building Networks ("Beyond")

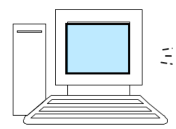
- How networks work
- Possible futures
- Proposed future

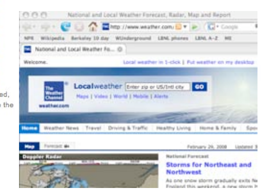


Overview

- Think Broadly about Networks ….

While some integrators are skeptical about the prewired, preprogrammed NHS rack from Sony, others embrace the solution for its simplicity.





How much energy does The Internet use?

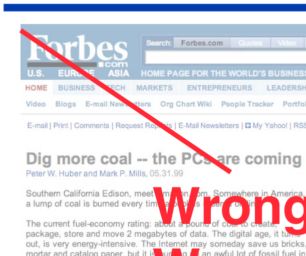
1999

"At least 100 million nodes on the Internet, … add up to … **8% of total U.S. demand**. … It's now reasonable to project that **half of the electric grid** will be powering the digital- Internet economy within the next decade."

emphasis added

2007

How much energy does The Internet use?



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"At least 100 million nodes on the Internet, … add up to … **8% of total U.S. demand**. … It's now reasonable to project that **half of the electric grid** will be powering the digital- Internet economy within the next decade."

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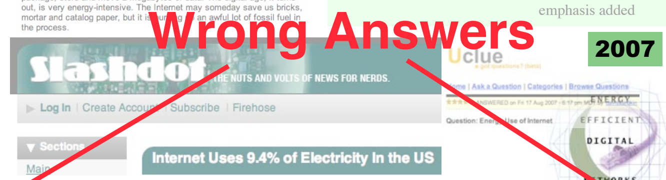
Wrong Question

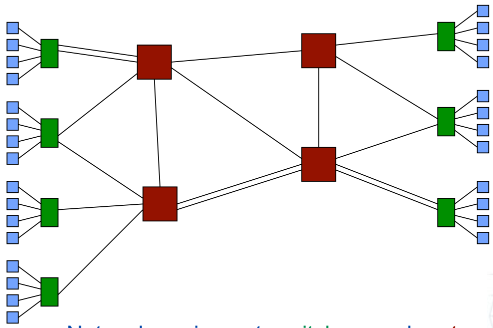
Wrong Answers

2007



Network Structure

- Edge devices: PCs, servers - Displays, storage, phones, …



- Network equipment: switches, and routers

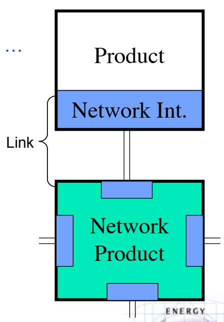
Some questions worth asking

- How much energy does all network equipment use?
  … telecom equipment? … edge devices?
- How much energy does network connectivity induce in edge devices?
- [How much energy does IT avoid]
- Where is all this headed?
- How much can we reasonably save in network eqt.?
  … in edge devices?
- What are research and implementation priorities?

Networks and Energy

Network equipment ….
Routers, switches, modems, wireless APs, …

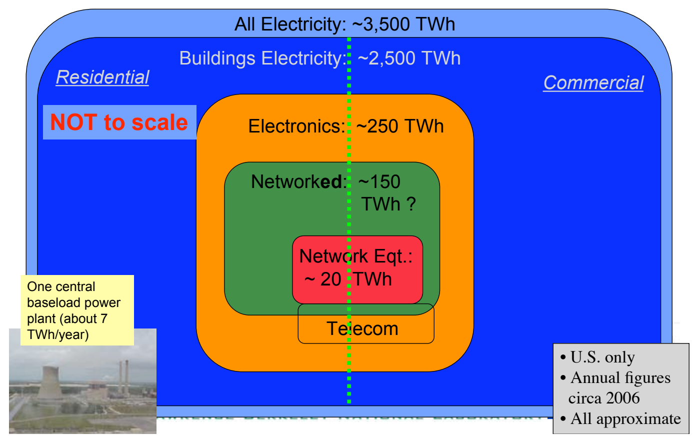
… vs **networked** equipment
PCs, printers, set-top boxes, …



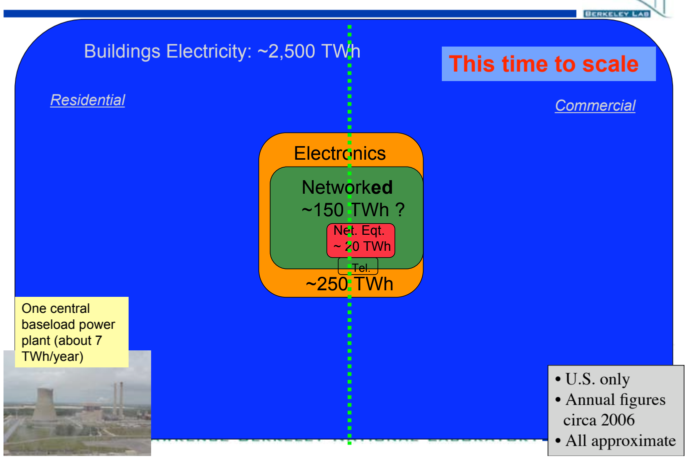
How networks drive energy use

- **Direct**
  - Network interfaces (NICs)
  - Network products
- **Induced** in Network<u>ed</u> products
  - Increased power levels
  - Increased time in higher power modes (to maintain network presence)

Network electricity use in context



Network electricity use in context, cont.



How much energy does network equipment consume?

(Bruce's best estimate)	*$billion*	*TWh/year*
Telecom	$0.80	8.0
Data center	**$0.20**	**2.0**
Residential	**$0.73**	**7.3**
<u>Commercial (office)</u>	**<u>$0.88</u>**	**<u>8.8</u>**
Subtotal	$1.80	18
IP Service providers (access, metro, core)	< ?	< ?

Total: ~20 TWh/year

- All of these figures <u>rough</u> estimates for 2006
- *None of this includes cooling or UPS*
- *$0.10/kWh used for convenience*

- **U.S. only — Global figures probably 3-5 times larger**

Things we know: Energy consumption is at edge

- Network equipment < 10% of all electronics
- Most electronics already networked
- More electronic — and non-electronic — devices getting networked
- Network *induced* consumption > all direct
- Network equipment energy will grow …
  … but other electronics will grow faster

Things we know: Utilization is low

- *Data networks are lightly utilized, and will stay that way*, A. M. Odlyzko, *Review of Network Economics*, 2003

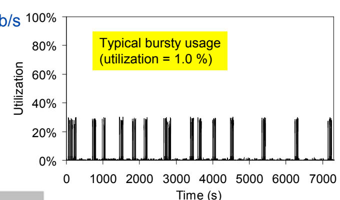
Network	Utilization
AT&T switched voice	33%
Internet backbones	15%
Private line networks	3~5%
LANs	1%

Low utilization is norm in life — e.g. cars

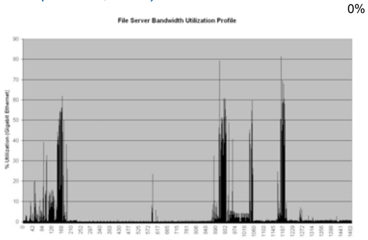
- Average U.S. car ~12,000 miles/year = 1.5 miles/hour
- If capacity is 75 mph, this is **2%** utilization

Things we know: Utilization is low, cont.

- Snapshot of a typical 100 Mb/s Ethernet link *(Singh)*



- File server link utilization (daytime) *(Bennett, 2006)*

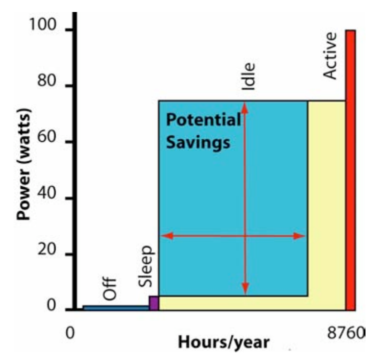


Conclusions (for edge links only)

- Bursty
- Very low average utilization

Things we know: Edge device energy is mostly idle

Core Fact: Most PC energy use occurs when no one present



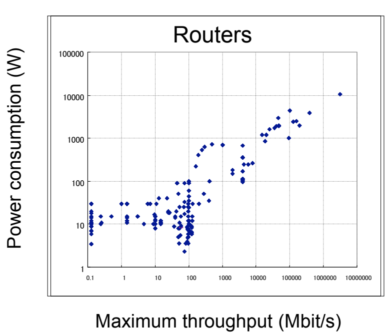
All time for year sorted by power level

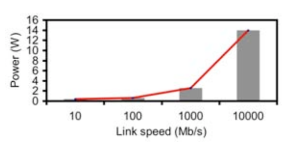
Most of time when idle, could be asleep

PC savings potential is **most** of current consumption

Similar patterns apply to set-top boxes, printer, game consoles, …

Things we know: Speed costs energy / power





Measured power of various computer NICs (averaged)

Source: Christensen, 2005

Source: METI, 2006

Energy cost is a function of capacity, not throughput

Things we know: IP will go everywhere

- IT equipment - IP already universal
- IP for phone calls (VOIP)
- IP for TV (IPTV)
- IP for consumer electronics generally
- IP for buildings (lighting, climate)
- IP for …..

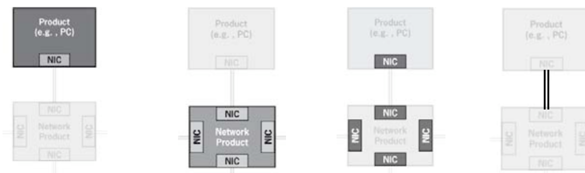
How should we think about networks and energy?

Approaches / Focus
- Device
  - AC*-powered products
- Link
  - Capacity, usage, distance, technology
- Throughput
  - Traffic totals, patterns, distribution
- Application / Protocol
  - Drivers of infrastructure, edge devices
- Context
  - In-use / not, time-sensitive / not, etc.

Essential to use all approaches simultaneously

Efficiency Approaches

Product Focus	Network Product Focus	Interface Focus	Protocol / Application Focus



Examples:

Proxying **Energy Star** Energy Efficient Ethernet **CE**

Need all approaches

Finding Energy Savings Opportunities

Sample approaches

- Relax assumptions commonly made about networks
  - when feasible (rarely in core); mine wireless technology
  - these assumptions drive systems to peak performance
    - average conditions require less energy
    - many assumptions tied to latency
- Design for average condition, not just peak
  - rely on data about typical use
- Use Network to gather info about savings opportunities
- Use Network to enable edge device savings

LBNL Projects

Network Connectivity "**Proxying**"
- Edge device savings

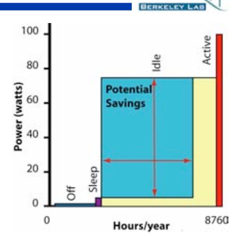
Energy Efficient Ethernet
- Link savings

Efficiency Specifications for Network Equipment
- Network equipment savings

Consumer Electronics
- Edge device savings

Network Connectivity "Proxying"

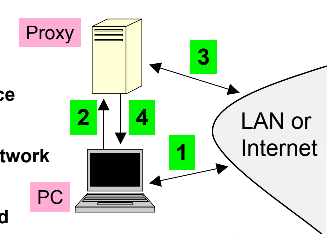
- Enable large majority of PC users to use sleep without breaking their own or IT admin applications
  - At least 80%. > 90% better. > 95% or > 98% even better.
- Enable both current and emerging common applications
- Enable standard to be used directly in (or easily adapted for) printers, set-top boxes, game consoles, etc.



Proxying, cont.

Proxy operation

1. **PC awake; becomes idle**
2. **PC transfers network presence to proxy on going to sleep**
3. **Proxy responds to routine network traffic for sleeping PC**
4. **Proxy wakes up PC as needed**



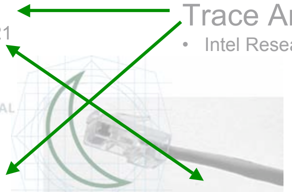
Proxy can be internal (NIC), immediately adjacent switch, or "third-party" device elsewhere on network

Proxy does: ARP, DHCP, TCP, ICMP, SNMP, SIP, ….

Proxying , cont.

Standard
- Ecma TC32-TG21

Trace Analysis
- Intel Research Berkeley

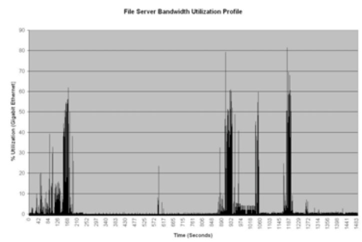


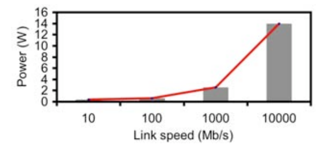
Use Cases
- In development

Prototypes
- Microsoft Research "Somniloquy"
- ???

Products: mid 2010 ?

Adaptive Link Rate

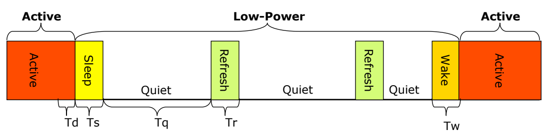




Observations
- Most of time, full link capacity not needed
- Notebooks already dropped link rate in sleep

Proposal (LBNL & USF)
- Enable changing link rate **quickly** in response to traffic levels
  *(**ms** not s)*

Energy Efficient Ethernet



- IEEE 802.3az created to standardize EEE
- Standards process began with ALR; eventually settled on alternate method "Low Power Idle"
  - Stop transmitting between packets
  - Switch now takes ***micro***seconds
- Standards process needs about 1 more year
  - Goal to get EEE technology into ALL Ethernet network hardware globally over next few years

Energy Efficient Ethernet

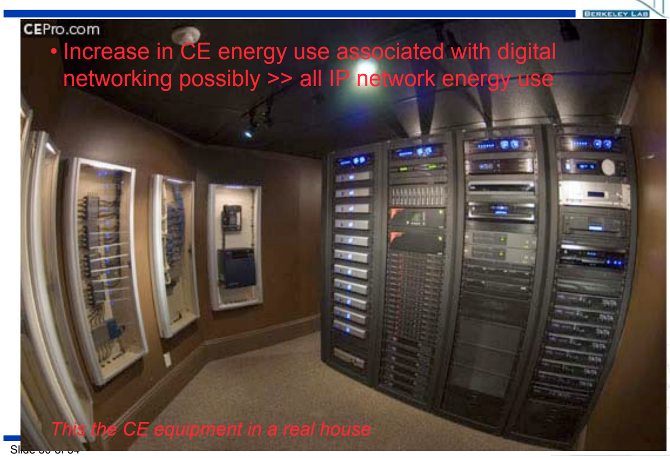
Efficiency Specs for Network Equipment

Today:
- Network equipment a growing electricity use in all sectors
- Companies increasingly claiming energy efficiency as a feature
- No current test procedures (no good ones)
- Very few efficiency specifications
- Little knowledge of networks in energy community

Efficiency Specs for Network Equipment, cont.

LBNL project:
- Estimate total energy use of network equipment in U.S.
  – Approximately 1% of total
- Identify product types with largest comsumption, largest potential savings, and ease of rating for efficiency
- Work with industry to develop standard test procedures
- Create community of interest on topic
- Hand off to Energy Star for spec process

Consumer Electronics



Our CE Future ?

While some integrators are skeptical about the prewired, preprogrammed NHS rack from Sony, others embrace the solution for its simplicity.

- Network / Data connectivity a Mess
- Number of CE devices is LARGE
- For energy use, digital networking could easily:
  - cause large increases, or
  - enable significant reductions
- We cannot rely on manual power control

Consumer Electronics – What to do

- Move to 3-state power model
- Address link power consumption
- Provide for persistent network presence
- Expose power state to network
- Standardize some user interface elements
  - Displays
- Create a model for standard behaviors / expectations for CE devices

Ask me later

Research Questions: Networks & Energy

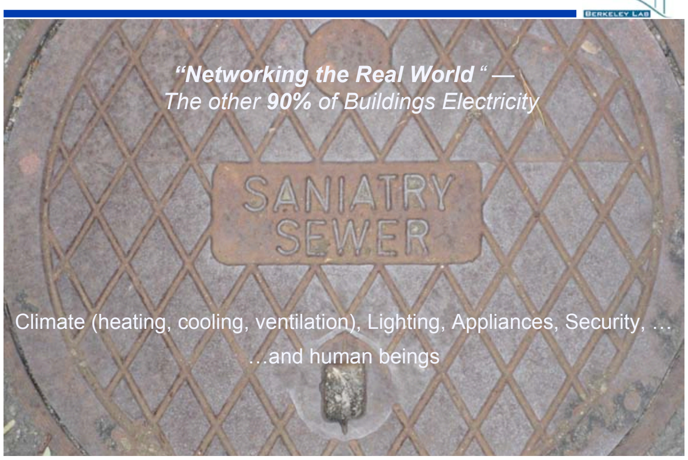
- Should low link utilization lead to any powering down of links?
- How much savings can be leveraged by introducing more latency? (when OK for application)
- Should power state be exposed to the network?
  - Embodied in protocols
  - Distinct sleep state with reduced network connectivity?
- Should a document of guiding principles be developed for protocols and other standards?
- Will security features or concerns sometimes trump energy efficiency?
- What intelligence in network should support energy efficiency in network equipment? in edge devices?

Summary – Electronic Networks

- Network energy use neither huge nor small
  - induced larger than direct
- Most energy use is at the edge
- Large savings possible - many approaches needed
- Most opportunity is at non-peak conditions
- Energy raises network architecture questions

Key collaborator: Ken Christensen, University of South Florida

Building Networks



The Two Great Domains: Information and the Real World

Object / Representation	Information	Real World
Information	e.g. airplane reservation IT networks	e.g. recipe, map, architectural drawing, … Building networks
Real World	e.g. airplane ticket, printed web page Paper	e.g. scale model ???

- To cross domain from real world to info world, need standard language, conventions, etc.

Building Networks – Overview

- Network Concepts
- Possible Futures
- Strawman Architecture
- Difficult Topics
- Next Steps

Building Networks

- **Electronics**
  - Products whose primary function is information (acquire, process, store, transmit, display)
- **Lighting** - sources, controls, shades
- **Climate Control** - sources, distribution, openings
- **Security**
- **Sensors**
- **Other** (Appliances, Misc.)
- **Human beings** (future: each human has IP address?)

- **Future: All one network**
  - separation for illustration only

Key Network Concepts, cont.

OSI Network Model

#	Name	Function
7	Application layer	"I want a web page"
6	Presentation layer	.
5	Session layer	.
4	Transport layer	.
3	Network layer	.
2	Data link layer	.
1	Physical layer	"Bits on a wire" (or non-wire) 1011100001010011111010100010101

(8th layer — User Interface)

Key Network Concepts, cont.

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Key Advantages
- Can replace individual layers without affecting higher and lower layers
- Facilitates interoperability
- All revolves around Internet Protocol

(8th layer — User Interface)

Past Experience with Networks

- **IT Networks**
  - Not designed with Energy in mind
  - Energy people not involved in design
  - "Tacking on" energy features not successful
  - Community not opposed to working with energy people
- **CE Networks**
  - A mess at all layers
  - Energy/efficiency not a priority
  - Progress possible if we do most work and use leverage
- **Sensor Networks**

Imagining the Future

- **Incrementalism** (alone) **the path to nowhere**
  - Need quantum leaps to make significant progress
  - Internet is a key example
  - Incrementalism is how to implement (not design)
- **Figure out where we want to get to …**
  - **… then chart path from here to there**

Let's consider two possible futures (2029) …

A “Darwinian” Future

*Highly networked buildings use **more** energy than others*

- Building networks installed principally for reasons other than saving energy
- Promoters of specific (physical layer) technologies pursue their advantage at the expense of interoperability
- Efficiency an afterthought in network and product design
- Energy efficiency not a major player in standards development
- User interfaces neglected
- Little coordination across end uses

An “Intelligent Design” Future

*Highly networked buildings use significantly **less** energy*

Based on open international standards, and have:

- Sensors for occupancy, temperature, and ambient light
- Controls that take into account *presence*
- Dynamic capabilities — temperature, light, façade, …
- Lighting that tracks activity
- Climate control that follows preferences, outdoor climate (to indicate clothing), and occupancy
- Preferences expressed through many means
- Displays coordinated with occupancy and lighting
- Diagnostics to ease coping with equipment failure

(Some) **Necessary steps for a good future**

- Adopt standard network technology up through TCP/IP (sensor networks a possible exception)
- Adopt goal of “universal interoperability”, across:
  - Countries, time, end uses, building types, etc.
- Be prepared to jettison any/all existing technology
- Engage network research community into design of network architecture for buildings
  - Create Building Network Task Force (BNTF) as sibling to Internet Engineering Task Force (IETF)
- Start on this ASAP

A sketch of a model

Network architecture for buildings

- Proposed 5-layer model for building control networks

	User Interface	*<= One Standard*
Diverse Standards =>	Applications	
	Communication*	*<= One Standard*
	Concepts*	*<= One Standard*
	Transport	*<= One Standard*
Diverse Standards =>	Network, Data Link, Physical	

- Policy and authority among multiple entities in buildings also key
- Global standards and diversity both essential for networks to be effective and usable

**Concepts may not be a true layer*

Transport - Physical Layers

- Don’t pick “winners”
  - But don’t be surprised by success of IEEE 802
- All buildings will have multiple wired and wireless physical layer technologies
  - Will evolve over time
- Sensor networks are a special case
  - This discussion does not apply

Concepts

- **Standardization of core ideas, terms, and underlying metaphors**
  - the meaning (semantics) of the information
  - not how it is encoded or represented (except in the UI)
- **Examples**
  - Building elements (energy using or not) - lights, climate control devices, windows, displays, and appliances
  - Ideas - presence, schedules, prices, and events
  - Characteristics - physical location, power levels, light
  - Existing example standard concepts
    - ASCII, fonts, folders, PDF, HTML
- **“Presence” a key concept**
- **A “vocabulary” of nouns**

Communication

- Transmit information about identity, status, characteristics, requests, …
- Negotiate policies about control
- "Location" a key issue

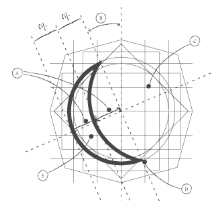
Application

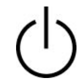
- Application layer is about making decisions
- Need to facilitate multiple models for decision-making
- Locus of authority a key issue

User Interfaces

- Consistent across:
  - Manufacturers
  - Products
  - Countries
- Simple
- Accessible
- Portable

"Universal"





Key Issues

- Presence
  - How to sense, indicate
  - Types
- Authority
  - Who has it? When?
  - Adapting to circumstances
- Security / Privacy
- Anomalies
  - Device failure
  - Emergencies

Good network architecture also needed for:

- Pricing
  - Direct
  - Externalities
- Demand Response

Next Steps

- Adopt Building Network design as a key efficiency priority
- Fund academic research on key topics
  - Presence, authority, security, user interfaces, network architecture, protocol design, …
- Create new institutions as needed
- Revisit related topics in light of this
  - Real-time pricing, demand response, "smart grids", …
- Get started ASAP

What about the "Smart Grid"

- If the "Smart Grid" stops at the meter:
  - I have nothing to say
- If the "Smart Grid" extends through the meter:
  - This is a very bad idea that will impede improvements in grid and in buildings
  - The meter is our friend

Thank you!

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